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Carbon Capture and Storage: A Controversial Climate Mitigation Approach

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Carbon Capture and Storage: A Controversial Climate Mitigation Approach

Jennie C. Stephens

As the threats of climate change grow, the need to reduce carbon dioxide (CO_2) emissions from fossil fuel burning is increasingly acknowledged by governments around the world. The potential of carbon capture and storage (CCS), a set of technologies that offers a politically appealing vision of a 'cleaner' way to use fossil fuels, has provided powerful motivation for large public and private investments in CCS technology. But investing in CCS is controversial because, although some consider it a critical climate mitigation technology, others view it as an expensive fossil fuel subsidy that could inadvertently perpetuate, rather than reduce, fossil fuel reliance.

Keywords: carbon capture and storage (CCS), climate mitigation, fossil fuels

The need to reduce greenhouse gas emissions is increasingly accepted as a societal objective as the threats of climate change become more apparent.[1] Given that carbon dioxide (CO_2), emitted primarily from fossil fuel burning for energy, is the greenhouse gas with the largest impact on the climate system, drastic change in energy systems is required to mitigate climate change. A transition away from fossil fuel-based energy systems toward renewable-based energy systems is underway, but the pathway and timeframe for this transition is uncertain and highly dependent on current decisions and investments. Given the heavy reliance on fossil fuels in many energy systems throughout the world, technological options that could eliminate or reduce CO_2 emissions of fossil fuel burning have broad appeal. Carbon capture and storage (CCS) emerged around twenty years ago as a technology with this potential.[2] CCS refers to a set of technologies designed to reduce CO_2 emissions from large point sources including coal-fired power plants by capturing the CO_2 and then storing the carbon in a reservoir other than the atmosphere.

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[1]Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2014 Mitigation of Climate Change,* 2014, https://www.ipcc.ch/report/ar5/wg3/.

[2]De Coninck and Benson, "Carbon Dioxide Capture and Storage"; Metz *et al.*, *IPCC Special Report*; Jaccard, *Sustainable Fossil Fuels*.

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For over a decade, several governments around the world have invested billions of dollars in developing CCS technology with the hope of reconciling sustained use of fossil fuels with climate mitigation objectives.[3] Many energy experts have projected that CCS is a technology critical to 'solving' climate change,[4] while scepticism about the high costs of CCS and the uncertain societal benefits are widespread.[5]

This article first explains the different components of CCS and the current status of technology development. Then a review of the arguments for and against continued investment in CCS is presented to describe the growing controversy of this climate mitigation strategy.

CCS development and current status

CCS incorporates various technologies associated with capturing and transporting CO_2 and storing the compressed gas somewhere other than the atmosphere. Most current conceptualisations of CCS focus on the potential of storing the CO_2 in underground geologic formations, although ocean storage and terrestrial storage have also been considered.[6] A complete CCS system involving geologic carbon storage includes four basic steps with different technologies required for each step: 1) capture the CO_2 from a power plant or other concentrated source, 2) transport the CO_2 gas from the capture location to an appropriate storage location, 3) inject compressed CO_2 gas into an underground formation and 4) monitor the injected CO_2 to verify its storage.

Technologies that are used commercially in other sectors are currently available for each of these components. CO_2 capture technology is widely used in ammonia production and several other industrial manufacturing processes. CO_2 gas has been transported through pipelines and injected underground for decades, most notably in West Texas where it is used to enhance oil recovery (EOR) of wells with

[3]Torvanger and Meadowcroft, "The Political Economy of Technology Support"; Markusson *et al.*, *The Social Dynamic of Carbon Capture*.
[4]Pacala and Socolow, "Stabilization Wedges"; Stangeland, *Why CO_2 Capture and Storage;* Gibbins and Chalmers, "Preparing for Global Rollout"; Global CCS Institute, *An Ideal Portfolio of CCS Projects*; Greenwald, Congressional Testimony on the Future of Coal; International Energy Agency (IEA), *Technology Roadmap: Carbon Capture and Storage*, 2013 edition, http://www.iea.org/publications/freepublications/publication/technologyroadmapcarboncaptureandstorage.pdf.
[5]Greenpeace International, "False Hope, Why Carbon Capture and Storage won't Save the Climate", Amsterdam, 2008, http://www.greenpeace.org/international/Global/international/planet-2/report/2008/5/false-hope-executive-summary.pdf; Folger, *Carbon Capture and Sequestration*; S. Goldenberg, "Can Kemper become the first US power plant to use 'clean coal'?", *The Guardian*, 12 March 2014, http://www.theguardian.com/environment/2014/mar/12/kemper-us-power-plant-coal-carbon.
[6]Metz *et al.*, *IPCC Special Report*.

declining production. Several CO_2 storage demonstration projects (including Sleipner in the North Sea and Weyburn in Saskatchewan, Canada) have been injecting millions of tons of CO_2 underground for several years.

Yet, the integration and scaling-up of these technologies to demonstrate CO_2 capture and storage with a power plant has been slower and more expensive than many had projected. It was not until October 2014 that the world's first commercial-scale demonstration of a coal-fired power plant with CCS began operation – the Boundary Dam Project in Saskatchewan.[7] This project, a 110MW retrofit of a coal-fired power plant, is viewed by many as a milestone for CCS development. Several other demonstration projects are coming close to operation; in the United States, for example, a USD5 billion coal-fired power plant project with CCS in Kemper County, Mississippi, is scheduled to come on line in early 2015,[8] and in Scotland the Peterhead project is moving toward the first full-scale natural gas power plant with CCS.[9]

The concept of engineering systems to deliberately capture and store CO_2 has evolved in the past twenty years from a relatively obscure idea to an increasingly recognised set of potential climate change mitigation options. The appeal of the potential of CCS to reconcile continued fossil fuel use with CO_2 emissions reductions has led to large government investments to advance CCS technology. Many of the countries that have invested the most in CCS are countries whose energy systems are heavily reliant on coal, including the United States, Australia, Canada and China.[10] Norway has also been a major investor in CCS, not because the country is heavily reliant on coal but because of their national-level involvement in oil and gas extraction in the North Sea.[11] The Global CCS Institute (GCCSI), which maintains a website with updated descriptions of current CCS projects around the world, reports that there are 13 large-scale CCS project in operation, nine others under construction, and an additional 33 in various stages of planning and development.[12] A public database maintained by the US Department of Energy's National Energy Technology Laboratory documents a total of 268 CCS projects in more than 30 countries, including proposed, active and cancelled projects.[13] These projects include 68 projects focused on CO_2 capture, 61 projects

[7]P. Black, "Worlds First Coal-fired Power Plant CCS Operation", *Process Industry Informer*, 1 Oct. 2014, http://www.processindustryinformer.com/latest-news/news-events/industry-news/worlds-first-coal-fired-power-plant-ccs-operation.

[8]Goldenberg, "Can Kemper become the first US power plant to use 'clean coal'?".

[9]"Shell signs agreement to advance major clean energy project at Peterhead", Shell, 24 Feb. 2014, http://www.shell.co.uk/gbr/aboutshell/media-centre/news-and-media-releases/2014/shell-signs-agreement-clean-energy-project-peterhead.html.

[10]Tjernshaugen, "Political Commitment to CO_2 Capture".

[11]Ishii and Langhelle, "Toward Policy Integration".

[12]GCCSI, *Global Status of CCS,* http://www.globalccsinstitute.com/projects/browse.

[13]Last updated January 2013, it includes both large- and small-scale projects, http://www.netl.doe.gov/research/coal/carbon-storage/cs-global/database.

focused on storage, and 139 projects that include both capture and storage. Most of these are proposed projects, or projects still under development, but more than 30 of them are active projects where CO_2 is being captured and/or injected underground.[14] Among the current priorities for advancing CCS are enhancing the capture process to reduce the energy intensity and cost of capture, demonstrating underground CO_2 capture in a geologically diverse set of geologic formations, and demonstrating and deploying integrated and scaled-up CCS power plant systems that allow for 'learning-by-doing'.

Bio-energy with CCS

Beyond CCS with fossil fuels, the possibility of combining bio-energy with CCS (BECCS) offers unique climate mitigation potential because it could actually drawdown and reduce CO_2 already accumulated in the atmosphere.[15] If carbon is captured and stored from a power-plant that is burning biomass, there could be net movement of CO_2 from the atmosphere to geologic formations. While CCS coupled with coal or natural gas offers possible reductions in carbon dioxide emissions, CCS coupled with bio-energy has been considered a negative emissions technology because it has potential to reduce atmospheric CO_2 concentrations.[16] Decoupling CCS research from fossil fuels and expanding CCS research related to bio-energy could reduce controversy regarding CCS investments because BECCS is more explicitly focused on the long-term climate mitigation potential of CCS. But to-date most CCS research and investments are focused on CCS with fossil fuels rather than CCS with bio-energy.

Growing CCS controversy in climate mitigation

The potential of carbon capture and storage to contribute to climate mitigation has provided powerful motivation for large public and private investments in CCS technology. But continued investment in CCS is becoming increasingly controversial as the scale and urgency of climate change grows and CCS advancement continues to be slow and expensive. Although some consider CCS a critical climate mitigation technology, others view it as an expensive fossil fuel subsidy that could inadvertently perpetuate, rather than reduce, fossil fuel reliance.[17]

Assumptions regarding future fossil fuel consumption patterns

As energy and climate experts explore future scenarios that result in a reduction in greenhouse gas emissions to a level that might keep global temperatures below an

[14]http://www.netl.doe.gov/research/coal/carbon-storage/cs-global/database.
[15]Vergragt *et al.*, "Carbon Capture and Storage".
[16]Azar *et al.*, "The Feasibility of Low CO_2".
[17]Greenpeace International, "False Hope"; Vergragt *et al.*, "Carbon Capture and Storage".

increase of 2°C, CCS emerges for some as an essential technology.[18] Due to embedded assumptions of a continued trajectory of fossil fuel use, some claim that climate goals cannot be reached without CCS.[19] But others question the dominant assumptions regarding continued fossil fuel consumption and point out that CCS is not essential in scenarios that assume drastic reductions in fossil fuel use.[20] In fact, analysis by the International Energy Agency shows that if CCS is not widely deployed, the only way that emissions can be reduced to prevent even less than a 2°C warming is if more than two-thirds of current proven fossil fuel reserves are kept in the ground.[21] While some view sustained fossil fuel consumption as inevitable and consider the possibility of not using proven fossil reserves as an impossibility, others are working toward and advocating for a future in which fossil fuel consumption will be drastically reduced. Controversy surrounding the desirability of CCS technology is due in large part to differences in assumptions regarding the potential for change in future fossil fuel consumption patterns.

The emergence of the possibility of CCS in the last twenty years has enabled many fossil fuel-dependent actors, particularly individuals and institutions in coal-dependent regions of the world, to stop denying the existence of climate change; CCS provides the possibility of continuing coal use while also addressing climate change.[22] Now with recent increases in natural gas reliance, CCS similarly offers the possibility of reconciling climate mitigation goals with growth in natural gas power plants.

The energy penalty and other CCS risks

The amount of energy required to capture and store CO_2 is one reason why many are sceptical of the optimistic perceptions of the potential of CCS. The so-called 'energy penalty' has been estimated to be about 30 percent within a range from 11 to 40 percent.[23] This means roughly that for every three coal-fired power plants utilising CCS, an additional power plant would be required simply to supply the energy needed to capture and store the CO_2. The magnitude of this energy penalty (including even the lower estimates) is so high that it is difficult to imagine a future scenario in which generating and then consuming this much additional energy to enable CCS would actually make sense.

Another set of risks associated with CCS relates to political difficulties in managing and preventing leakage of the underground storage of CO_2 for thousands of

[18]IEA, *CO_2 Emissions from Fuel Combustion*, and *Technology Roadmap*.
[19]"IEA hails historic launch of carbon capture and storage project", IEA, 2014, http://www.noodls.com/viewNoodl/25284530/iea—international-energy-agency/iea-hails-historic-launch-of-carbon-capture-and-storage-proj.
[20]Greenpeace International, "False Hope".
[21]"IEA hails historic launch of carbon capture and storage project", IEA, 2014.
[22]Stephens, "(CCS) in the USA".
[23]House *et al.*, "The Energy Penalty".

years after it is injected.[24] Optimism about the potential of CCS is based primarily on research on technical feasibility, but less attention has been paid to the socio-political requirements of regulating and enforcing long-term monitoring and maintenance of CO_2 stored underground.[25] Global institutional structures with the capacity to enforce liability for thousands (or even hundreds) of years do not exist. And political instability, corruption, and inevitable tensions among countries create severe and constant risks of any proposed global CO_2 storage management scheme.

The health and safety risks of perpetuating the use of fossil fuels represent other drawbacks.[26] The large, industrial-scale, fossil fuel power plants that CCS is being designed to enable cause major health and safety risks to both the communities surrounding the plant (including water and air pollution) and those impacted by fossil fuel extraction (including coal mining, hydraulic fracturing for natural gas extraction and fossil-fuel transport).[27] Strong public concern about the health and safety risks of storing CO_2 underground has derailed several large-scale CCS demonstration projects in the past four years including the Vattenfall project in Germany and the Barendrecht project in the Netherlands.[28] In addition, concern about earthquakes triggered by injection of large volumes of CO_2 underground is motivating enhanced technical understanding of the risks of leakage.[29]

Detracting from the renewables transition?

The vision of CCS as an essential part of climate mitigation has also enabled complacency about the growing dangers of sustained fossil fuel dependence. And many are concerned that the enormous amounts of government funds devoted to CCS could have been invested, instead, in facilitating and encouraging the transition toward renewable-based energy. The energy transition toward more renewable-based systems demands technical change but also social and cultural change, so investments of all kinds at multiple societal levels are needed to move away from fossil fuel dependence. Given the uncertainty associated with future costs and applications of CCS and the long-time horizon for realising actual greenhouse gas reductions from CCS, some view investments in reducing energy demand and expanding renewable energy technologies as offering more concrete, near-term societal benefits that would be less risky.

CCS investments have been recognised as one of many fossil fuel subsidies[30] that need to be reduced to encourage a transition to more renewable-based energy

[24]Wilson *et al.*, "Research for Deployment".
[25]Wilson *et al.*, "Regulating the Ultimate Sink"; IEA, *Carbon Capture and Storage.*
[26]Muller *et al.*, "Environmental Accounting for Pollution".
[27]Markandya and Wilkinson, "Electricity Generation and Health".
[28]GCCSI, *Global Status of CCS Projects.*
[29]Zoback and Gorelick, "Earthquake Triggering"; National Research Council of the National Academies, *Induced Seismicity Potential.*
[30]Victor, *Politics of Fossil-Fuel Subsidies.*

systems. As the need to reduce fossil fuel reliance is increasingly acknowledged for climate reasons, as well as human health and geopolitical reasons, CCS investments are also viewed by some as incentivising continued use of fossil fuels. By reinforcing fossil fuel infrastructure, these investments may also create a questionable sense of optimism promoting the notion that our current fossil-based energy systems can be safely continued.

Costs and timeframe

Widespread CCS deployment remains a distant and expensive possibility.[31] While some view the Canadian Boundary Dam Project, the first full-scale power plant with CCS that came on line in October 2014, as a historic demonstration of the potential of CCS, others see this project as reflecting the improbability of CCS ever becoming commercially viable due to the exorbitant costs that required huge government subsidies, and the prolonged timeframe for this first full-scale demonstration plant. The total project cost has been estimated at USD1.24 billion with several million being contributed by the federal and provincial governments and costs being recovered by selling the captured CO_2 for enhanced oil recovery.[32] Whether the Boundary Dam project reflects the stark challenges of advancing CCS or the promising potential of CCS is dependent on the diverging perspectives regarding the value of CCS investments.

For sceptics, the slow pace and high cost of demonstrating CCS results in a problematically long time-horizon for scaling up CCS deployment to the point that any significant climate mitigation benefits can be realised.[33] CCS has often been described as a ‘bridging’ technology to provide CO_2 reductions during the transition to renewable-based energy systems. But the past decade of slow progress suggests to some that building the CCS bridge may take longer than the transition to renewables.[34]

In the current global economic situation, government expenditure of the magnitude required to advance CCS is becoming more difficult to justify. A single CCS demonstration plant is estimated to cost on the order of one billion dollars, and those advocating more investment in CCS are asking governments to spend USD3-4 billion each year for the next decade.[35] Considering all the other ways that this level of investment could be spent to advance and support shifts toward renewable energy, public investments in CCS are facing additional scrutiny.

[31]Boretti. “Is There any Real Chance”; GCCSI, *Global Status of CCS*; Scott *et al.*, “Last Chance for Carbon Capture”.
[32]MIT, “Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project”, 2014, https://sequestration.mit.edu/tools/projects/boundary_dam.html.
[33]Watson, *Carbon Capture and Storage*.
[34]Boretti, “Is There any Real Chance?”.
[35]Nauclér *et al.*, *CCS Assessing the Economics*; and IEA, *Technology Roadmap*.

Controversial and uncertain future

Advocating for government support for CCS technology has become a passionate priority for many deeply committed, technologically optimistic energy professionals. This optimism makes sense for those who believe the dominant narrative that continuing growth of coal and sustained consumption of fossil fuels is inevitable due to its low cost, abundance and reliability.[36] In this narrative, coal offers unique potential to continue to expand electricity access in the developing world, providing unparalleled economic development opportunities. One problem with this narrative is that the extremely negative social, economic, environmental and human health impacts of coal[37] are dismissed and not explicitly integrated or acknowledged.

As the risks and impacts of climate change become more apparent, accelerating a transition away from fossil fuels to renewable-based energy systems must become a priority not only to mitigate climate change but also to enhance resiliency. During this transition, all energy investments must be carefully considered with regard to their long-term influence on energy system change.

As we attempt to prepare ourselves for dramatic changes ahead, some long-held assumptions regarding the inevitability of future fossil fuel consumption may need to be re-evaluated.

Scepticism about the societal value of investing billions of dollars in CCS, an expensive fossil fuel focused technology, is growing. The private sector has recognised the many risks of CCS and has only been willing to invest in CCS in conjunction with strong government investment.

At the same time as scepticism is growing, an international CCS advocacy coalition remains influential and continues to frame CCS as an essential part of any climate change mitigation portfolio. As the international climate change community anticipates the upcoming United Nations Framework Convention on Climate Change conference of the parties in Paris in December 2015, CCS continues to be centrally integrated into discussions of the convention's Technology Executive Committee and Technology Mechanism.[38] And the United States' and China's bilateral 2014 climate change agreement included enhanced commitment to collaboration on advancing CCS.

Despite these developments, the future of CCS remains uncertain and controversial. As urgency in climate mitigation grows, some activists are calling for different assumptions about fossil fuel use, energy consumption patterns, and how to facilitate and accelerate the transition to renewable-based energy systems. Depending on how these societal discussions develop, priorities related to advancing CCS could change. Some of the controversy surrounding CCS could be reduced if CCS

[36] IEA, *World Energy Outlook 2013*.
[37] Muller *et al.*, "Environmental Accounting for Pollution".
[38] Jacoby and Chen, *Expectations for a New Climate Agreement*.

advancement were decoupled from fossil fuels and refocused on CCS with bio-energy; investments in BECCS rather than CCS with fossil fuels would ensure that future CCS initiatives contribute to long-term climate mitigation rather than inadvertently perpetuating fossil fuels.

From a technological perspective, it has been suggested that the infrastructural requirements and inflexibility of CCS could exacerbate "technological lock-in" to fossil fuel use.[39] From a political perspective, the sunk-costs associated with the amount of money already invested in CCS also creates "political lock-in". For governments and institutions that have already invested millions or billions of dollars and considerable political capital to advance CCS, continued support appears likely despite growing scepticism about the societal risks of advancing CCS.[40]

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[39]Meadowcroft and Langhelle, *Caching the Carbon*.

[40]Pollak *et al.*, "Carbon Capture and Storage Policy"; Stephens *et al.*, "Characterizing the International".

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